Remote Sensing: Principles and Applications
Prof. R. Eswar
Department of Civil Engineering and Interdisciplinary
Program in Climate Studies
Indian Institute of Technology-Bombay

Lecture-06
Introduction of EMR with Atmosphere

Hello everyone, welcome to today's video on the topic Interaction of electromagnetic radiation with the atmosphere. In this particular lecture we will be talking about how EMR interacts with the various constituents of the atmosphere and its influence on remote sensing that we do. In the last lecture we saw that whenever EMR is travelling is through a lossy medium then it will undergo scattering and absorption. That is the total energy of EMR will be reduced by these 2 processes. Atmosphere contains several gases, dust particles, aerosols and other constituents which will interact with the electromagnetic radiation and reduce its final intensity.

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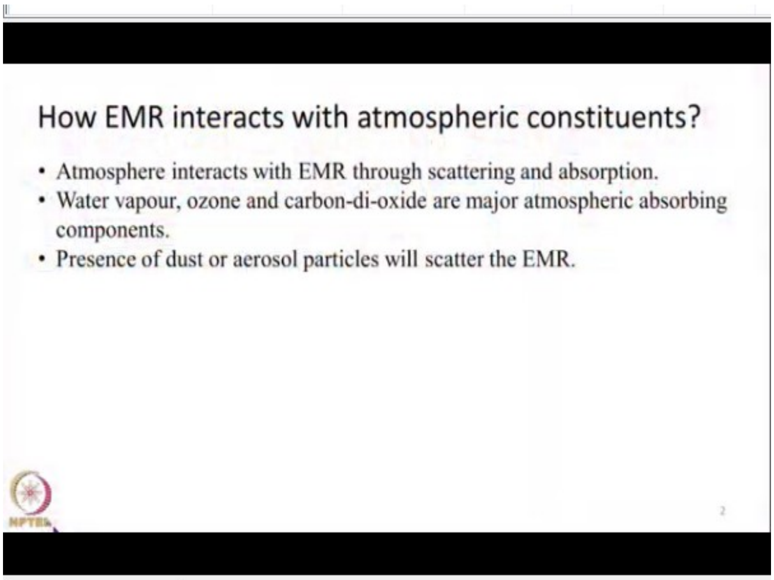

So, as I said atmosphere will interact with electromagnetic radiation through scattering and absorption. How scattering will occur? Scattering will occur because of presence of tiny gas molecules or aerosol particles. Aerosol means some sort of dust may be present, like wind may be blowing carrying some dust particles or like when people burn stubble, it will create dust. All these things are called aerosols basically.

So, when aerosols, gas molecules or like rain drops, ice particles etc are present in the atmosphere they cause scattering. Similarly the gas molecules present in the atmosphere such as CO_2, water vapor etc. will absorb some amount of radiation for changing its nature to some extent. So, energy will be both absorbed as well as scattered.

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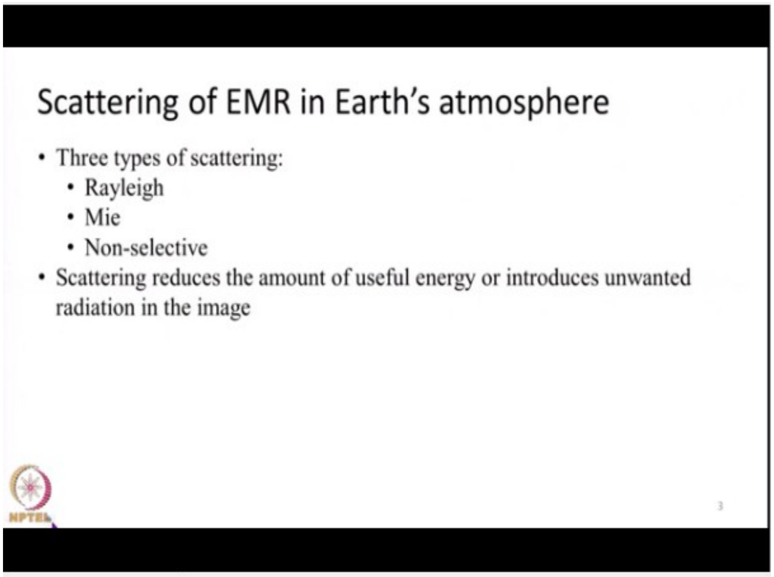

First we will see about scattering in the atmosphere. The scattering of EMR in the atmosphere can be classified into 3 types rayleigh scattering, mie scattering and non selective scattering. So, those 3 are listed here in this slide. Rayleigh, mie and non-selective, the 3 types of scattering that occurs in the atmosphere. As you have already studied scattering reduces the amount of useful energy.

That is say light rays coming in this particular direction, the presence of gas molecules or dust here will scatter this radiation in different, different direction and if we are like placing some sensor here, the net energy coming in the direction will be reduced. So, scattering reduces the amount of useful energy in the given intended direction and also introduces some unwanted radiation in the image. Unwanted radiation in the sense say here radiation is scattered in different directions, after some time this scattered radiation will reach the surface through different means or with different intensities. So, basically scattering at one hand reduces the amount of energy coming in the particular direction. On the other hand it adds some component of scattered energy like all points on the earth's surface will receive some energy in addition to sun's direct energy. This additional energy is actually coming in from the radiation that is left in the atmosphere itself through scattering. So, what are these 3 types of scattering? First we will start with rayleigh scattering.

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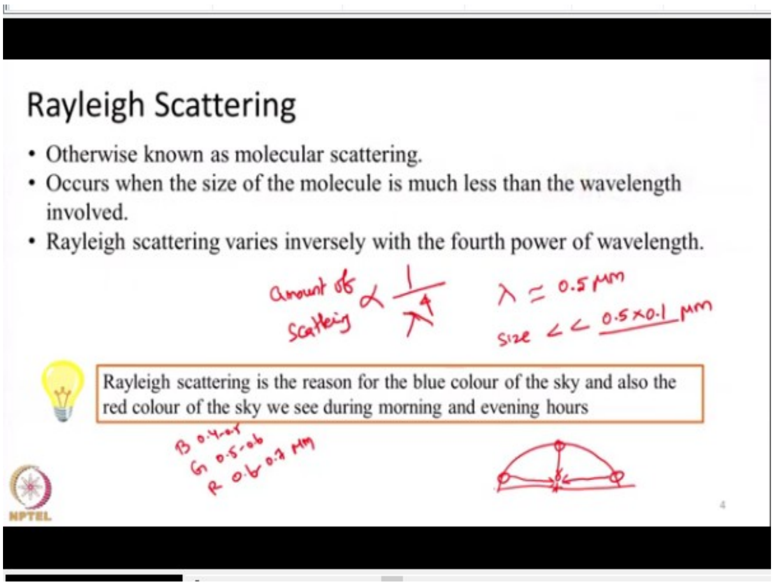

Rayleigh scattering is also known as molecular scattering, as the name suggests this scattering occurs due to tiny gas molecules present within the atmosphere. When the size of the molecules is too small, that is less than 10 times of the wavelength involved, say if the wavelength of the electromagnetic radiation is around 0.5 micrometer, if the molecule size is much less than or one tenth of the wavelength of incoming EMR, then this particular EMR will undergo Rayleigh scattering. So, rayleigh scattering will happen when the molecules have a size much smaller than the wavelength that is coming and interacting with the molecule and this rayleigh scattering varies inversely with the fourth power of wavelength. That is,

$$Amount\ of\ Scattering\ \alpha\ \frac{1}{\lambda^4}$$

that is as the λ becomes smaller and smaller the amount of scattering will be keep on increasing. If we take visible light, it consists of 3 colors primary colors blue, green and red 0.4 to 0.5 micrometers, 0.5 to 0.6 micrometers and 0.6 to 0.7 micrometers. This is the wavelength range of these 3 primary colors as we know.

And we normally see the sky is bright blue color. If the sky is really clear without lot of clouds and dust particles around we see the sky as blue in color. This is primarily because of rayleigh scattering. I just listed the wavelength of 3 primary colors blue green and red. Among these 3 which our eyes can see blue has the shortest wavelength. So, the amount of scattering that blue undergoes is much higher than the amount of scattering that green or red will undergo.

Hence what will happen when the sunlight enters the atmosphere carrying blue, green and red, blue will be scattered to a larger extent at the top of the atmosphere itself and only the remaining portion will reach us. So, the blue is now scattered all along the atmosphere itself, it is not reaching the earth's surface. That is why we see the sky as blue in color. Blue is now scattered entirely on the atmosphere.

Similarly during evening time like sunset and sunrise time we will be seeing the sky as bright red in color. This is because whenever during morning or evening the sun will be at the horizon, the distance between or the distance through which the light has to travel is much more than during day time. I will give a small example here, say this is the land surface let us put a hemisphere around the land surface and some observer is standing here. If the sunlight is overhead, the distance the light has to travel is much less. On the other hand, if the sun is at horizon the distance light should travel is much longer. So, as the distance through which the light travels increases, amount of scattering will also increase. Because as the distance becomes larger and larger the interaction will be increasing and as interaction increases scattering and absorption will be more basically.

So, due to this increased path length what will happen, first blue will be scattered and it will be left in the atmosphere itself, then green and red will be passing through. Even green will be scattered because of this longer path length only red will escape the scattering because of its longer wavelength and it will reach our eyes. That is the reason we see the morning and evening sky as red in color. So, rayleigh scattering is the primary reason for these color appearances and the amount of rayleigh scattering varies with respect to fourth power of wavelength.

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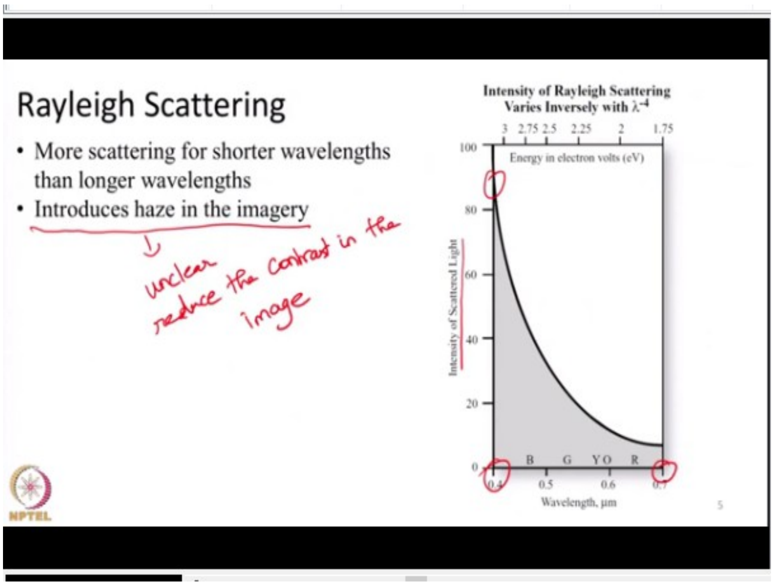

As I said before here in this slide I am just explaining the amount of scatter like the intensity of scattered light is much higher at shorter wavelengths and it is much lower at longer wavelengths. So, the main problem of rayleigh scattering for remote sensing is it introduces haze in the imagery.

Haze means the image will be unclear, it will have some sort of a dusty appearance, it will reduce the contrast in the imagery. The haze effect will reduce the contrast in the image. So, we will see there a reduction in contrast, what effect it has and all briefly in some other lectures later in the course.

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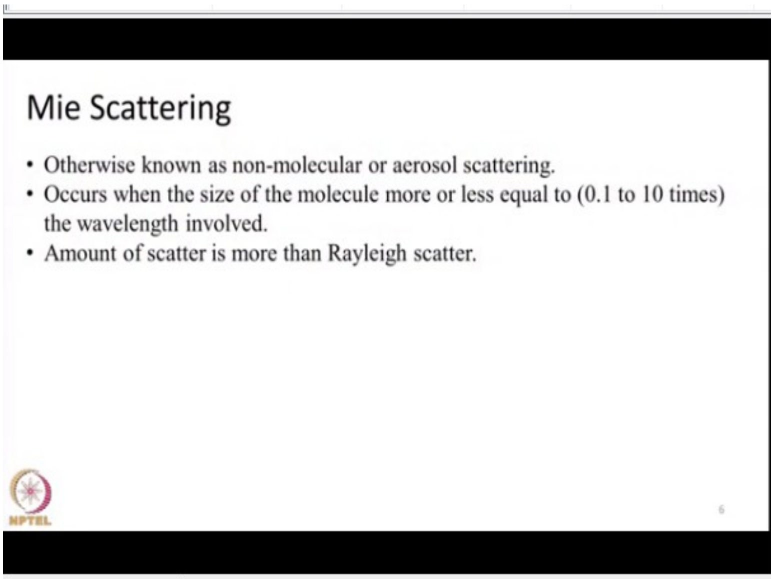

Next we are going to see about mie scattering. Mie scattering is also known as aerosol scattering or non-molecular scattering. So, this type of scattering occurs when the size of the molecule is 0.1 times to 10 times the wavelength involved. So, here there is like a lower bound and upper bound of size of the molecule. So, here the size of the molecule will vary from 0.1 times to 10 times the wavelength involved. Then these sort of molecules will actually cause mie scattering.

Mostly the presence of dust in the atmosphere causes mie scattering whenever dust is present or some aerosol particles is present we see lot of disturbance in our vision that is basically due to mie scattering and in mie scattering the intensity of scatter will be much higher than rayleigh scattering. Whenever there is a dust storm passing through before our eyes you will not be able to see anything because of lot of blockage will be there and lot of energy will be scattered. So, the amount of scattering will be much higher in mie scattering.

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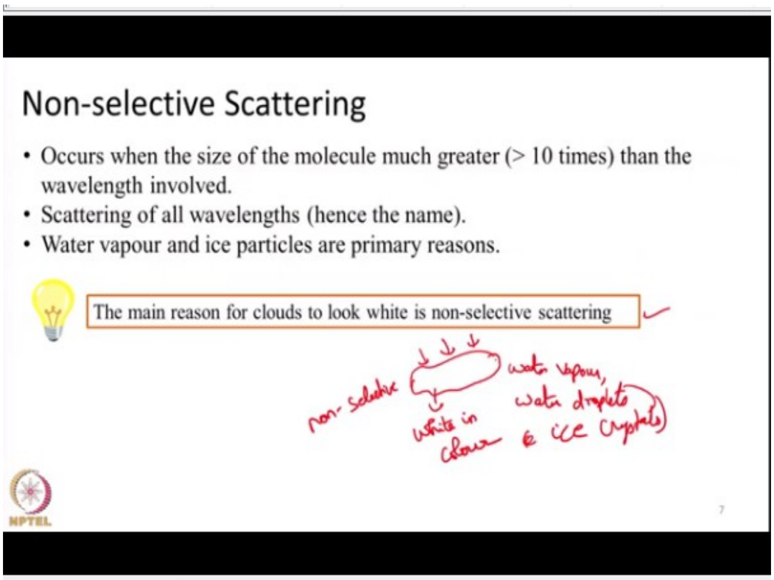

Then the final type of scattering is called non-selective scattering. Non-selective scattering some text books treat it as an extension of mie scattering. Non- selective scattering will happen when the size of the molecule involved is more than 10 times the wavelength involved, like the molecules is much bigger in comparison to the wavelength involved and non-selective scattering as the name suggests will scatter all the wavelengths equally like it will not have any sort of wavelength dependence it will scatter all wavelengths equally.

So, what are the primary materials that causes non-selective scattering, larger particles such as ice crystals in cloud or water droplets such things which are much bigger than the wavelength of EMR will cause non-selective scattering. One important or interesting point to notice the main reason for clouds to look white is non selective scattering. That is clouds if we look at primarily composed of water vapor, water droplets and in some clouds ice crystals will also be there.

So, all these things water droplets and ice crystals and all will scatter all the incoming radiation equally, non-selective scatter will happen and because of this we see clouds as white in color. Why white in color, the primary colors that we see as red, green, blue, when these 3 things mix equally we perceive it as white in color. So, since all the wavelength that is coming in or scattered equally when our eyes see it we will see a equal mixture of red, green and blue and we see clouds as white in color.

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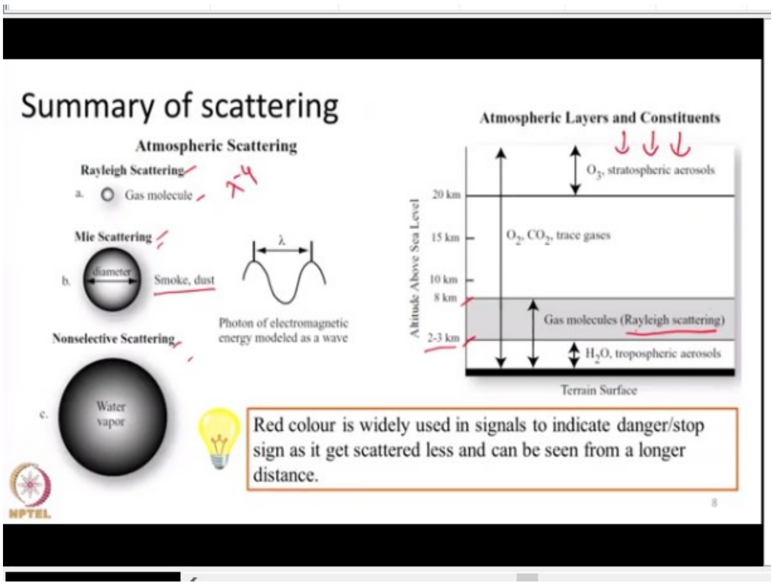

So, just to do like a summary of scattering. So, scattering is 3 types rayleigh, mie or non selective. The primary particles that causes rayleigh scattering is gas molecules, for mie scattering it is the dust or smoke and for non selective scattering it is water vapor, ice crystals etc. Rayleigh scattering varies with wavelength, non-selective scattering and mie scattering are relatively non dependent on wavelength especially non-selective scattering.

And if you look at the atmosphere levels the different layers of atmosphere like from the surface and up to 20 kilometers is given in this particular figure. So, when the electromagnetic radiation from the sun is coming in the top portion of atmosphere it consists primarily of gas molecules. So, mostly rayleigh type of scattering will occur in the top portion of the atmosphere.

When it is coming in say here like about 8 kilometers above the surface of the atmosphere will be containing lot of gas molecules, hence here also rayleigh scattering will be happening. Once it comes very close to the surface within like last 2 to 3 kilometers within the surface, the EMR will encounter water particles, dust particles and everything which will cause mie scattering and non selective scattering.

So, rayleigh scattering happens relatively higher up in the atmosphere and mie scattering happens relatively lower to the surface much closer to the surface okay. So, one more interesting fact I wanted to tell you is why red color we use widely in signal to indicate danger or stop sign is because red is scattered the least when we compare the 3 primary colors we can see blue, green and red.

Red is scattered to the least among these 3 colors, whenever the scattering happens red will encounter the smallest amount of scattering due to which red wavelengths can travel for longer distances because of this particular reason people have chosen red to indicate danger sign. So, that say if someone is travelling in a vehicle, red light will appear from a much longer distance itself. So, they will see the red light from a longer distance and they will start the process of breaking. In order to give a clear indication to the user, red is being used as a sign for danger or stop signal.

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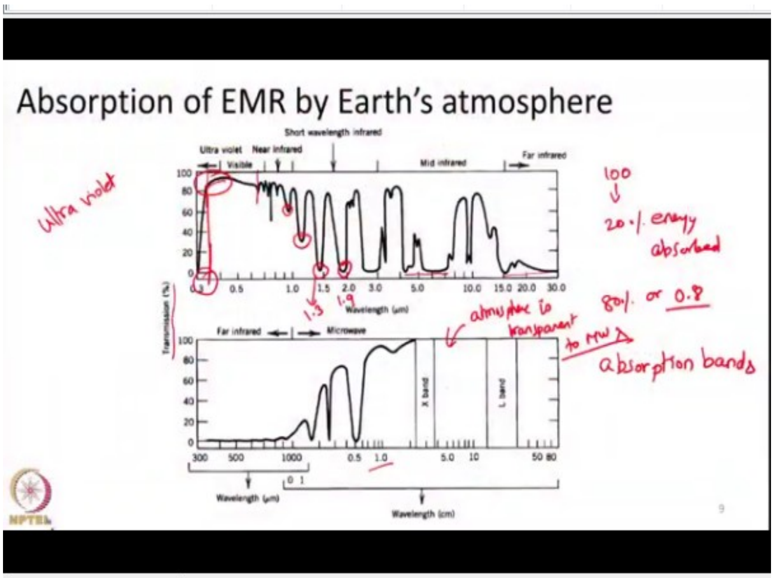

Next we are going to see is the absorption of EMR by earth's atmosphere. So, as I said before atmosphere consists of lot of gas molecules O_2 oxygen molecules, water vapor, carbon dioxide, ozone and many more are there. Due to the presence of such materials each of them will interact with electromagnetic radiation and they will absorb certain portion of EMR.

So, in this particular figure in this slide I have presented how EMR is transmitted and how the transmission varies with wavelength. So, transmission is, if some amount of energy is coming in say some 100 units of energy is coming in, let us assume 20% of energy is absorbed. So, we call transmittance as 80% or 0.8 as a fraction. So, what is the amount of energy that is left after absorption we call it as transmission.

So, transmission is given here in this percentage, we can see from this particular figure that the transmission of the atmosphere varies a lot with wavelength. At smaller wavelengths like less than 0.4 which we call it as the ultraviolet region, the transmission of the atmosphere is very low like the transmission is less than 5 or 10%, atmosphere is almost opaque to UV radiation. This is because of the presence of ozone in the atmosphere.

So, the ozone absorbs almost all the UV radiation incident on it thereby saving the living organisms on the earth surface from the harmful nature of UV radiation. So, ozone effectively absorbs almost all of UV radiation. After UV part if we come to the visible portion of the spectrum we still we can see that our transmission is relatively higher like after you cross this particular portion.

After you cross this particular portion the transmissivity is actually very high it is in the range of like 80 to 90%. In the visible part, 0.4 to 0.7 micrometer we are having like a very good transmissivity in the atmosphere. So, that is why we will be getting most of the visible energy from the sun without much hindrance. Atmospheric absorption is much lower in the visible portion.

After the visible portion, after 0.7 micrometers and all there are like very sharp absorption features here. Around 1.3 or 1.4 micrometers there is a very strong absorption feature. So, atmosphere presents a characteristic dips in different, different portions. So, wherever atmospheric transmission is very low we call such portion as absorption bands.

Say for example around like 1.3 to 1.4 micrometers there is a very strong absorption where the transmission is very low or the absorption is very high this we call it as an absorption band similarly around 1.9 micrometers there is a very high absorption band in the atmosphere. So, such energy coming in 1.3 to 1.4 micrometers or 1.9 micrometer wavelength those energies will not even reach the earth's surface from the sun.

So, whenever sunlight is coming through the atmosphere these particular wavelengths which are highly absorbed by the atmosphere will not reach the earth's surface they will be stopped completely in the atmosphere itself. So, again we go back to this figure. So, here in this figure you can see after like around 3.5 or 4 micrometers atmosphere is fairly opaque. Opaque in the sense transmittivity is very low.

And after say 15 micrometers or something there is like a huge gap, here the transmissivity is extremely low. Then when we enter the microwave portion of the spectrum the transmission suddenly goes up like after one centimeter wavelength we can see the transmission of the atmosphere is fairly high. So, atmosphere is transparent to microwave wavelengths.

So, microwave essentially is free from atmospheric absorption. So, the amount of absorption that is undergone by microwave is extremely low because atmosphere is fairly clear, on the other hand if we come to shorter wavelengths such as like visible IR or MWIR portions there are characteristic bands at which the atmosphere of molecules will absorb radiation. Such characteristic bands are called absorption bands. And the energy contained within such absorption bands will not reach the earth's surface it will be absorbed completely in the atmosphere.

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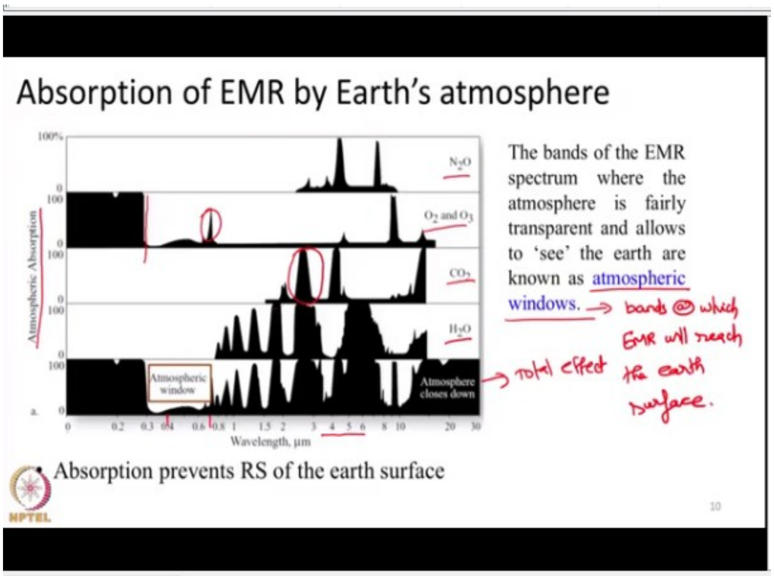

So, this particular slide is actually a mirror image of the past slide. In the past slide I showed you atmospheric transmission here I am showing you atmospheric absorption because of the different gas molecules that is present. So, here the atmospheric absorption is now divided into its constituent components which causes atmospheric absorption at which wavelength.

So, this is the total effect of all particles or all molecules together and these first 4 figures are due to the individual molecular components. Say for example N_2O nitrous oxide is the main reason for absorption in the mid wave infrared wavelength around like 4 micrometers, oxygen and ozone O_2 and O_3. O_3 is the primary reason for absorption in shorter wavelength or UV radiation.

Oxygen is the primary absorption in around like 0.6 micrometers. Similarly CO_2 is a very strong absorber of around like 2 to 3 micrometers, H_2O was the primary cause of lot of small atmospheric absorption windows around like say 1 micrometer, 1.3 micrometers, 1.9 micrometer is a very strong water vapor absorption band, similarly between 2 to 3 micrometers all such bands are absorbed due to H_2O.

So, each molecule absorbs different, different portion of wavelengths and since atmosphere is a mix of all these molecules the final effect that we see is a collective one of all these gases, that is given in the last portion of the slide. So, for example if we take the visible portion around 0.4 to say 0.7 micrometers the absorption is very low and we can receive that particular wavelength in earth's surface.

So, such portions where the atmosphere is fairly transparent and allows the EMR to enter the atmosphere and reach the earth's surface are known as atmospheric windows. So, the atmospheric windows are the wavelength bands at which EMR will reach the earth surface. In atmospheric absorption bands EMR will be stopped in the atmosphere itself. In atmospheric windows EMR will be allowed to reach the earth's surface by the atmosphere.

Hence if we want to practice or if you want to do remote sensing of earth surface then essentially we should design sensors which should be able to sense the energy in this atmospheric windows, we cannot put sensors in the atmospheric absorption bands if we want to see the earth's surface.

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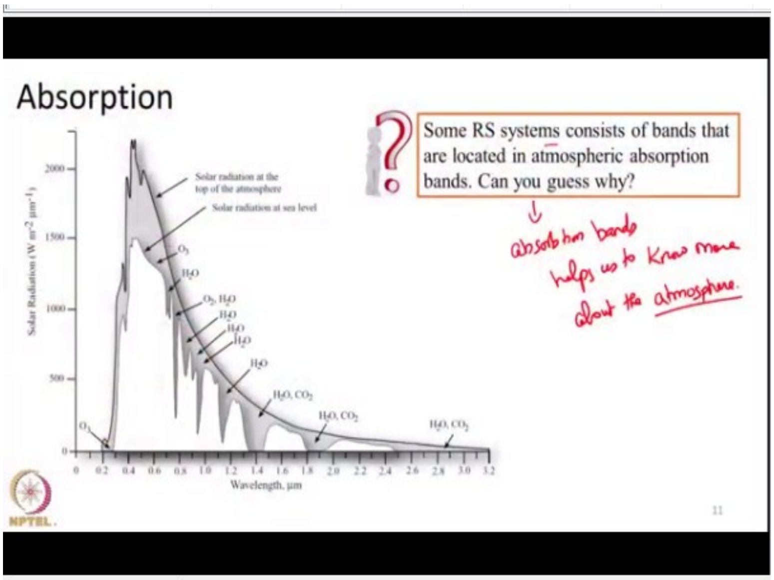

So, this is again the absorption with respect to wavelength given in this particular slide. One interesting question I wanted to ask. Some remote sensing systems consist of bands that are located in atmospheric absorption bands can you guess why? Please take few seconds pause the video and think over it. The main reason for putting some bands centered around this atmospheric absorption bands is to get more information about the atmosphere itself.

So, such absorption bands helps us to know more about the atmosphere, like how much CO_2 absorption is occurring will help us to model the presence of CO_2 content. Similarly the presence of water vapor will help us to monitor water vapor movement. Water vapor movement is the primary reason for rainfall in different places. So, for remote sensing of atmosphere it is quite natural to put few bands in center around in this atmospheric absorption bands.

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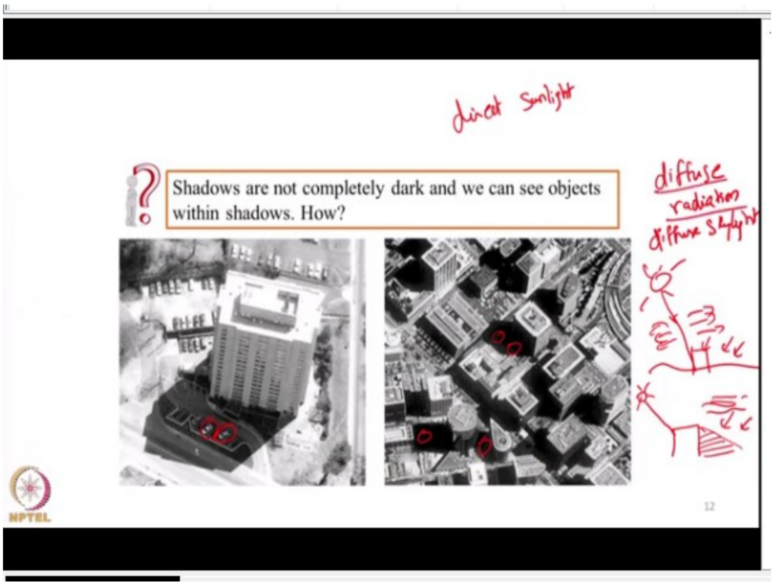

Before we close down I just want to put one more question to you. We discussed about atmospheric scattering and atmospheric absorption just related to that this question will be. The question is, in this particular slide, the shadows that we see are not completely dark and we can see objects within shadows. There is a tall building and the shadow is falling on the ground, still we can see whatever is there in the shadow. So, why the shadows are not completely dark? What is the energy that is falling on those objects? Please pause the video and think for a few seconds before knowing the answer. So, the answer for the question is the light scattering present in the atmosphere is a primary reason for irradiating the objects within the shadows.

That is, if there is a land surface and sun's direct radiation will be coming in, it will be scattered all along the atmosphere. And after some time this scattered radiation will come and fall down. say for example there is a building here and sun is giving its energy. So, this building will cast a shadow here and this portion will not receive sun's energy.

At the same time the scattered light present all across the atmosphere will be falling on the objects within the shadow portion and that is why we are able to see objects within the shadows. So, this sort of scattered radiation that is falling on an object, we call it as diffuse radiation or diffuse skylight.

The direct radiation from the sun we call it as direct sunlight and the energy that earth surface receives because of the scattered radiation we call it as diffuse radiation or diffuse skylight.

Because of the presence of diffuse radiation or diffuse skylight we are able to see objects within the shadows.

So, just to summarize today's lecture, we have learnt about scattering and absorption taking place in the atmosphere. Scattering is divided into rayleigh, mie and non-selective scattering. Scattering essentially removes the energy in one particular direction and redistributes it in several directions. So, scattering will remove some energy and also will add some energy again in form of diffuse skylight. Similarly absorption will also remove the energy in certain wavelengths completely. So, such wavelengths which are completely absorbed by atmosphere will not be useful for remote sensing of earth's surface.

For remote sensing of earth's surface we need to design bands such that they fall in atmospheric windows that is where the atmosphere is fairly transparent. With this we end this lecture.

Thank you very much.